SECTION 7

SUMMARY AND RECOMMENDATIONS

7.0 Summary and Recommendations

7.1 Overview

This report describes the potential health and environmental effects caused by uranium mines. It considers all contaminants--solid, liquid, and airborne--and presents doses and health effects caused by wastes at both active and inactive mines. In addition to outlining the various methods of mining uranium, the report graphically depicts mine locations and lists the U.S. total of 340 active and 3,389 inactive urainum mines (Appendixes E and F) according to mine name, owner, location (state, county, section-township-range), and total ore production. Table 7.1 summarizes the mine lists.

Several facts and limitations helped shape the method and approach of this study. Little information on uranium mines is available; measurement information that is available on uranium mine wastes is frequently influenced (biased) by nearby uranium mills; there are inherent variations between uranium mines, especially between in situ mines, that complicate generic assessments of uranium mine wastes; and, finally, the law (P.L. 95-604) that mandated this study allotted only a short time in which to complete it. To accommodate these facts in our study plan, we decided to develop conceptual models of uranium mines and to make health and environmental projections from them, based upon available data from the literature; to employ conservative (maximizing) assumptions when necessary; and to supplement available information with information from discussions with persons inside and outside the agency and by doing several field studies in Texas, New Mexico, and Wyoming. Table 7.2 summarizes the sources of uranium mine contaminants that were modeled in this study.

7.2 Sources and Concentrations of Contaminants

7.2.1 Surface and Underground Mines

We calculated released radioactivity for two models of active underground and surface uranium mines. The average-large mine, the first model, reflects new and predicted future mines. The average mine, the second model, reflects the regional impact of multiple mines. The quality and

Table 7.1 Distribution of United States uranium mines by type of mine and state

State	Active				Inactive		
	Surface	Underground	In situ leaching	All Others[a]	Surface	Underground	All Other[a]
Alaska	0	0	0	0	0	1	0
Arizona	1	1	0	0	135	189	2
California	0	0	0	0	13	10	0
Colorado	5	106	0	4	263	902	52
Florida	0	0	0	0	0	0	1
Idaho	0	0	0	0	2	4	0
Minnesota	0	0	0	0	0	0	1
Montana	0	0	0	0	9	9	0
Nevada	0	0	0	0	9	12	0
New Jersey	0	0	0	0	0	1	0
New Mexico	4	35	0	3	34	142	12
N. Dakota	0	0	0	0	13	0	0
Oklahoma	0	0	0	0	3	0	0
Oregon	0	0	0	0	2	1	0
S. Dakota	0	0	0	0	111	30	0
Texas	16	0	8	1	38	0	4
Utah	13	108	0	3	378	698	17
Washington	2	0	0	0	13	0	0
Wyoming	19	6	3	2	223	32	10
Unknown	0	0	0	0	6	5	2
Total	60	256	11	13	1252	2036	101

[a] Includes mine water, heap leach dumps, miscellaneous, and unknown.

Table 7.2. Sources of contaminants at uranium mines

Source	Active Underground	Active Surface	Inactive Underground	Inactive Surface
Waste Rock (Overburden) Pile				
Wind suspended dust	M	M	M	M
Rn-222 emanation	M	M	M	M
Precipitation runoff	C	C	C	C
Sub-Ore Pile				
Wind suspended dust	M	M	M	M
Rn-222 emanation	M	M	M	M
Precipitation runoff	C	C	C	C
Ore Stockpile				
Wind suspended dust	M	M	M	M
Rn-222 emanation	M	M	M	M
Precipitation runoff	C	C	C	C
Abandoned Mine Area Surfaces				
Rn-222 emanation	M	M	M	M
Mining Activities				
Dusts	M	M	NA	NA
Combustion products	M	M	NA	NA
Rn-222	M	M	NA	NA
Wastewater				
Surface discharge	M	M	NA	NA
Seepage	C	C	C	C

Note.--M, Source modeled; C, considered but not modeled due to lack of information; NA, not applicable.

flow rates that were determined for water discharges from typical surface and underground mines in Wyoming and New Mexico, respectively, were used to calculate chemical loading of streams in three hydrographic units: sub-basin (containing the mines), basin, and regional basin. Infiltration of mine water to potable groundwater and suspension/solution of contaminants in flood waters are the main components of the aqueous pathway. Crude dilution and infiltration models were used to evaluate aqueous discharge from active mines. Off-site movement from inactive mines is primarily by overland flow, the contamination significance of which was evaluated with limited field and literature surveys.

Concentrations of radionuclides and stable elements in waste rock, sub-ore, and ore, selected from only a few measurements, are shown in Table 7.3. Average annual airborne emissions for the sources listed in Table 7.2 were computed for active and inactive mines using the concentrations listed in Table 7.3 and the geological and meteorological information appropriate for each region. Source terms were maximized by assuming no dust control and no spoils pile restoration. Annual emissions of airborne contaminants estimated for the various sources are given in the following tables of Section 3.

	Tables on Active Mines		Tables on Inactive Mines	
Source	Surface	Underground	Surface	Underground
Combustion Products	3.30	3.52	--	--
Vehicular Dusts	3.32	3.56	--	--
Dust from Mining Activities	3.33	3.54	--	--
Wind Suspended Dust	3.34	3.55	3.70	3.76
Radon-222 Emissions	3.35	3.51	3.74	3.77

Annual emissions in mine water discharged to the surface by the model average underground and surface mines are listed below.

Parameter	Surface Mine (Wyoming)	Underground Mine (New Mexico)
Flow rate, m^3/min	3.0	2.0
Uranium-238, Ci/yr	0.037	0.49
Uranium-234, Ci/yr	0.037	0.49
Radium-226, Ci/yr[b]	0.00065	0.0014
Radon-222 and each short-lived daughter, Ci/yr	0.00065	0.0014
Lead-210, Ci/yr	0.00065	0.0014
Polonium-210, Ci/yr	0.00065	0.0014
Arsenic, Kg/yr	7.9	13
Barium, Kg/yr	ND[a]	850
Cadmium, Kg/yr	6.3	7
Molybdenum, Kg/yr	ND	300
Selenium, Kg/yr	ND	70
Sulfate, MT/yr[b]	276	122
Zinc, Kg/yr	112	45
Total suspended solids, MT/yr	33.0	29

[a]No data available.

[b]The values shown for radium-226 and sulfate are 10 percent and 20 percent, respectively, of those released on an annual basis. Radium is assumed to be irreversibly sorbed, and sulfate readily infiltrates.

Table 7.3. Concentration of contaminants in waste rock (overburden), ore, and sub-ore

Nonradioactive

Stable Element	Concentration, µg/g Waste Rock	Concentration, µg/g Ore and Sub-ore	Stable Element	Concentration, µg/g Waste Rock	Concentration, µg/g Ore and Sub-ore
Arsenic	9	86	Manganese	485	960
Barium	290	920	Molybdenum	2.5	115
Cadmium	NA	ND	Potassium	7,000	25,000
Cobalt	NA	16	Lead	22	78
Copper	18	61	Ruthenium	NA	ND
Chromium	< 51	20	Selenium	2	110
Iron	6,000	15,700	Strontium	150	130
Mercury	< 8	ND	Vanadium	100	1,410
Magnesium	NA	3,500	Zinc	20	29

Radioactive

Radioactive Contaminant	Concentration, pCi/g Waste rock	Concentration, pCi/g Sub-ore	Concentration, pCi/g Ore
U-238 and each daughter	6	(a)	285
Th-232 and each daughter	1	2	10

[a] The concentration of U-238 and each daughter was assumed to be 99 pCi/g at active underground mines, 40 pCi/g at active surface mines, and 110 pCi/g at inactive mines of both types.

Note.--NA, Not available; ND, Not detected.

7.2.2 In Situ Leach Mines

The sources of airborne releases that we assessed at our model in situ leach mine were the uranium recovery and packaging unit, the evaporation ponds, and the surge tank. The annual releases for these sources are listed below.

Source	Annual Airborne Release Rate
Recovery Plant	
Uranium-238	0.10 Ci
Uranium-234	0.10 Ci
Uranium-235	0.0048 Ci
Thorium-230	0.0017 Ci
Radium-226	0.00010 Ci
Lead-210	0.00010 Ci
Polonium-210	0.00010 Ci
Ammonia	3.2 MT
Ammonium chloride	12 MT
Carbon dioxide	680 MT
Surge Tank	
Radon-222	650 Ci
Storage Ponds	
Ammonia	100 MT
Ammonium chloride	300 MT
Carbon dioxide	80 MT

Since in situ mining is site specific and relatively new, little information is available on its wastes. Thus, only airborne releases were assessed quantitatively; liquid and solid wastes were discussed qualitatively.

Several chararcteristics of in situ mining, especially regarding its liquid and solid wastes, tend to minimize its release of contaminants.

First, only a small fraction of Ra-226 is leached (2.5 percent assumed); second, all liquid wastes are impounded with no planned releases; third, much of the liquid waste evaporates, except at a few sites in Texas where the wastes are injected into deep wells; and, finally, at in situ mines solid wastes accumulate at a much lower rate than they do at conventional mines. Aquifer restoration and underground excursion of the leaching solution were also discussed qualitatively. Although restoration has not yet been done at a commercial scale site, preliminary experiments indicate that proper aquifer restoration is possible. During the restoration process, Rn-222 will continue to be purged from the aquifer and should be considered a possible source of exposure.

7.2.3 Uranium Exploration

During exploration and developmental drilling, dusts are produced, Rn-222 and combustion products from drilling equipment are released, and approximately 0.2 hectares of land surface are disturbed per drill hole. The average mine site produces an estimated 6,100 kg of airborne dust, 20 kg of which is ore and subore. About 3400 Ci of Rn-222 are released annually from all development holes drilled since 1948 (4.5×10^5), which is similar to that released from one operating mine. Combustion product releases are small.

7.3 Exposure Pathways

Exposures were assessed for a hypothetical most exposed individual living about 1600 m (1-mile) from the center of the mine and for a population residing within an 80-km (50-mile) radius of the mine. The meteorological and geological parameters used were those appropriate to the respective sites.

Aqueous releases were modeled through a basin, sub-basin, and regional basin hydrographic area. Dilution by precipitation, snowmelt, and periodic flooding (typical of semiarid regions) was analyzed but not used in the model. For the model we assumed that the average annual release of contaminants is diluted by the average annual flow rate of the stream being considered. The pathways that we assessed are listed below.

Air Pathways

1. Breathing
   a. Radioactive particulates and radon-222
   b. Radon-222 daughters
2. External Exposure
   a. Submersion
   b. Surface deposited radioactivity
3. Eating
   a. Above-surface foods grown in the area
   b. Milk and beef cattle grazing in the area

Water Pathways

1. Breathing
   a. Resuspended contaminants deposited from irrigation water
2. External Exposure
   a. Submersion in resuspended contaminants deposited from irrigation water
3. Eating
   a. Above-surface foods grown in the area
   b. Milk and beef cattle grazing in the area and drinking contaminated water
   c. Fish

In addition to the risks caused by wastes at or discharged directly from the mines, we assessed the risks to occupants of habitable structures built on land containing uranium mine wastes. The radium-226 in these wastes increases the concentrations of radon-222 and its decay products and the gamma radiation inside these structures.

7.4 Potential Health Effects

7.4.1 Radioactive Airborne Emissions

The risks of fatal cancer were estimated for radioactive airborne emissions. They include the lifetime risk to the most and average exposed individuals in the regional population and the number of additional fatal cancers in the regional population caused per year of model mine operation (see Table 7.4).

The major fatal cancer risk at each of the model uranium mines is the risk of lung cancer from Rn-222 daughter exposures (Tables 6.11 and 6.12). At surface and in situ mines, radioactive particulates plus Rn-222 contribute only a little over 10 percent of the total fatal cancer risk. The principal radionuclides in the airborne particulate emissions are U-238, U-234, Th-230, Ra-226, and Po-210. The contribution from Th-232 and its daughters is minor. At underground mines, essentially all the risks are due to Rn-222 daughter exposures. Fatal cancer risks at active underground mines are greater than those at active surface mines because of the larger quantity of Rn-222 daughter products released. For inactive mines, the risks are similar at surface and underground sites.

Most of the exposure to individuals around the model uranium mines is received internally, usually by breathing. However, the average person in the region around surface mines receives most of his exposure by eating contaminated foods. The largest contributors to the radioactive particulate plus Rn-222 impact are ore and overburden at active surface mines and ore and sub-ore at the active underground mines. For the model in situ mine, the uranium processing plant was the main source of particulate radionuclides.

Of all evaluated model uranium mines, the average large underground mine (Table 7.4) causes the largest fatal cancer risk and the largest number of additonal cancers in the regional population. Compared to the natural occurrence of fatal cancer from all causes (Table 7.5), we estimate an increase of 1.3 percent (0.0019) in fatal cancers over the lifetime of the maximum individual and a 0.0003 percent (0.018) increase in fatal cancers in the regional population per year. Increases in expected fatal cancers are less at all other model mine sites.

Compared to a normal occurrence of genetic effects of 0.06 effects/birth and 12.1 effects/year in the regional population (Wyoming), the computed risk of additional genetic effects from radiation exposure at the model uraninum mines is very small. The average large surface mine produces the largest increase in genetic effects. We estimate the genetic risk to the descendants of the most exposed individual to be an additional 6.4E-5 effects/birth (0.1 percent increase) for a 30-year parental exposure; 2.2E-7 effects/birth (0.00036 percent increase) to the descendants of the average exposed individual in the regional population for the same

Table 7.4 Summary of fatal cancer risks from radioactive airborne emissions of model uranium mines

Source	Most exposed individual lifetime fatal cancer risk (a)	Average exposed individual lifetime fatal cancer risk (a)	Fatal cancers cancers caused in regional population per year
Average Surface Mine	1.3E-4	2.5E-7	1.7E-4
Average Large Surface Mine	4.2E-4	8.1E-7	6.4E-4
Average Underground Mine	2.0E-4	9.1E-7	1.7E-3
Average Large Underground Mine	1.9E-3	8.6E-6	1.8E-2
Inactive Surface Mine	3.4E-5	6.3E-8	1.3E-5
Inactive Underground Mine	2.0E-5	8.6E-8	4.5E-5
In Situ Leach Mine	2.2E-4	3.9E-7	3.1E-4

(a) Lifetime exposures were calculated as follows:
Surface and underground mines: Exposure for 17 years to active mining and 54 years to inactive mine effluents.
Inactive mines: Exposure for 71 years to inactive mine effluents.
In situ leach mine: Exposure for 10-year operation and 8-year restoration.

Table 7.5 Percent additional lifetime fatal cancer risk for a lifetime exposure to the individual and the percent additional cancer deaths in the regional population per year of exposure estimated to occur as a result of uranium mining

Source	Most Exposed Individual	Average Exposed Individual	Regional Population
Average surface mine	8.7E-2	1.7E-4	7.9E-6
Average large surface mine	2.8E-1	5.4E-4	3.0E-5
Average underground mine	1.3E-1	6.1E-4	3.1E-5
Average large underground mine	1.3	5.7E-3	3.3E-4
Inactive surface mine	2.3E-2	4.2E-5	6.1E-7
Inactive underground mine	1.3E-2	5.7E-5	8.3E-7
In situ leach mine	1.5E-1	2.6E-4	1.4E-5

Note.--Comparisons are based on the risks given in Table 7.4, a national cancer risk from all causes of 0.15, and an estimate of the cancer death rate from all causes to the regional populations of New Mexico (5,400 deaths) and Wyoming (2,140 deaths).

exposure period; and 7.9E-5 additional genetic effects committed to the descendants of the regional population per year of mine operation. The latter increase is very small compared to the 12.1 effects that will normally occur each year in the live births of the regional population.

7.4.2 Nonradioactive Airborne Emissions

Atmospheric concentrations of nonradioactive air pollutants were calculated at the location of the most exposed individual. The concentrations were compared with calculated nonoccupational threshold limit values, natural background concentrations, and average urban concentrations of selected airborne pollutants in the United States.

Of the pollutant sources investigated, three produced insignificant health hazards:

1. airborne stable trace metals
2. airborne combustion products from heavy equipment operation
3. nonradioactive gas emissions at in situ leach mines

However, at active surface mines, dust particulates (produced mainly by vehicular traffic) equal or exceed conservatively calculated nonoccupational threshold limit values and, therefore, are a potential nuisance.

7.4.3 Radioactive Aqueous Emissions

The only water from active uranium mines is that pumped from the mines and released to surface streams. The largest radiation dose* from this water to individuals in the assessment regions is to the endosteal cells (bone) (see Tables 6.25 and 6.26). It primarily comes from eating foods grown on land irrigated by streams fed by discharged mine water. Significant, but of lesser importance, are exposures due to breathing wind suspended material from irrigated land, eating fish caught in streams near the site, and external gamma radiation from land irrigated by streams fed by mine water discharges. We estimate only a small risk from eating beef and milk from cattle grazing on irrigated pasture and drinking water contaminated by mine discharges ($<$ 2 percent of the total risk from aqueous emissions). The radionuclides of major importance in the risk analyses are U-238 and U-234.

*In Section 7, "dose" is to be read as "dose equivalent"--absorbed radiation (dose) multiplied by a quality factor.

The risks of fatal cancer were estimated for radioactive aqueous discharges to surface streams from active uranium mines. The estimates included, for the 17-years of active mine operation, the cumulative risk to the most and average exposed individuals in the assessment area and the number of fatal cancers caused to persons residing within the assessment area (Table 7.6). Aqueous emissions from inactive mines and from in situ leach mines were not modeled due to a lack of data. However, we believe aqueous source terms from these mines would be low.

Drinking water may be an important source of exposure for the most exposed individual living near a uranium mine. However, we did not estimate it because we could not quantify radionuclide concentrations in potable groundwater with available information. Also, mine water probably is not consumed directly by man.

Table 7.6 Summary of the fatal cancer risks caused by radioactive aqueous emissions from model uranium mines

Source	Most exposed individual's lifetime fatal cancer risk for 17 years of mine operation	Average exposed individual's lifetime fatal cancer risk for 17 years of mine operation	Fatal cancers caused in the assessment area population from 17 years of mine operation
Underground mine site (New Mexico)	5.6E-6(3.7E-3%)[a]	3.4E-7(2.3E-4%)	2.2E-2(2.3E-4%)
Surface mine site (Wyoming)	1.2E-7(8.0E-5%)	1.6E-8(1.1E-5%)	2.6E-4(1.1E-5%)

[a] All "risks" in this table are in addition to the 0.15 risk of fatal cancer from all causes.

Although aqueous discharges from the model underground mine produce greater risks than those from the model surface mine, primarily because of greater releases of U-238 and U-238 daughters, aqueous releases at either mine cause only very small cancer risks (see Table 7.6) beyond the 0.15

natural risk of fatal cancer. For example, in New Mexico (assessment population 64,950) and Wyoming (assessment population 16,230), 9,742 and 2,434 deaths from cancer from all causes are projected to occur. Aqueous mine discharges in these areas will add only 0.022 and 0.00026 estimated deaths, respectively, to these totals.

The largest increase in estimated genetic effects occurs at the underground mine site. However, compared to the natural occurrence of hereditary disease, the overall risk of additional genetic effects due to radionuclides discharged in water from the model mines is very small. Based on a natural occurrence of 0.06 effects/birth, there will be 936 genetic effects in the regional population of New Mexico during 17 years of mine operation. In contrast, there will be only 0.015 additional effects to all the descendants of the regional population because of the 17-year exposure period.

7.4.4 Nonradioactive Aqueous Emissions

Aqueous concentrations of nonradioactive pollutants were calculated for stream water we assumed was used by the average individual within the assessment area. The pathways considered are those listed in Section 7.3. Drinking water might be a significant pathway for the most exposed individual. However, we could not make a reliable prediction of increased groundwater concentrations due to mine dewatering with the available data.

A comparison of the water concentrations of several pollutants with recommended EPA limits for livestock and irrigation usage (see Table 6.29) showed that only molybdenum from the underground mine approaches its limit for irrigation. The sums of the ratios of the average water concentrations to the recommended limits are less than one, indicating that mixtures of the metals would not exceed a "composite limit" for an average individual in the assessment areas. Constituents such as solids and sulfates, for which limits are unavailable, have minimal or no toxic properties.

More information is needed before definitive conclusions can be reached about health hazards caused by nonradioactive waterborne emissions. Uranium, the metal estimated to be in highest concentration, has no established limits based on chemical toxicity in the United States. Of particular interest would be data on water use patterns near the mines and the degree to which mine discharges may infiltrate groundwater supplies.

7.4.5 Solid Wastes

We estimated the risk of fatal lung cancer to individuals living in houses built on land contaminated by uranium mine wastes as a function of the Ra-226 concentration in the wastes (see Table 7.7). How much mine waste has been used for homesite land fill as well as its level(s) of contamination are unknown. Because of the cost, it is unlikely that mill-grade ore would be available for off-site use. It is more likely that waste rock, perhaps mixed with some sub-ore, would be the material used. Considering the Ra-226 content of sub-ores and the likelihood of its being diluted with waste rock and native soil, mine wastes in residential areas would probably contain between 5 to 20 pCi/gm of Ra-226.

Table 7.7 Estimated lifetime risk of fatal lung cancer to the average person living in a home built on land contaminated by uranium mine wastes

^{226}Ra in Soil (pCi/g)	Indoor Working Levels (WL)	Lifetime Risk of Fatal Lung Cancer[a]
5	0.02	0.025
10	0.04	0.050
20	0.08	0.10
30	0.12	0.15

[a] Based on the average individual being inside his home 75 percent of the time.

7.5 Environmental Impacts

We evaluated the environmental effects of uranium mining, including exploration, by reviewing completed studies, extensive communications with State and Federal agencies, field studies in Wyoming and New Mexico, reconnaissance visits to Wyoming, Colorado, New Mexico, and Texas, and imagery collection and interpretation. Underground and surface mines were examined to develop a sense of an average or typical condition with respect to mine size, land areas affected, quality and quantity of airborne and waterborne releases, and general, qualitative appreciation for the effects of such operations on surface streams, groundwater, disturbed land areas, and natural recovery processes. In many instances, conditions can be documented, but the significance remains highly subjective and thus weakens the justification for corrective action, particularly for inactive mines.

7.5.1 Land and Water Contamination

We conclude that (1) U.S. uranium mills make little use of mine water; (2) mine drainage is to the environment, with occasional use for agriculture, sand backfilling, construction, and potable supply; (3) active surface mines in Wyoming and underground mines in New Mexico have the greatest discharge to the offsite environment; (4) inactive surface mines do not appear to adversely affect groundwater quality, although water in such mines is typically contaminated and runoff from surface accumulation of overburden and sub-ore may be a source of surface water contamination; and (5) selected inactive underground mines in Colorado and possibly adjacent portions of Utah may discharge water enriched in radionuclides and trace elements. Since the mining industry now uses terrestrial ecosystems extensively as sinks for mining-related contaminants, an appropriate government agency should monitor active mines for groundwater quality, sorption of contaminants on stream sediments, and the flushing action of flooding events.

Before and during surface and underground uranium mining, contaminated mine water is frequently discharged to arroyos and pasture lands adjacent to the mines. Less frequently, mine water is used in nearby uranium mills, in which case ultimate disposal is to the mill tailings pile where evaporation and seepage occur. However, despite this practice of mine water discharge to land and despite the existence of over 3,000 active and inactive mines and the accelerating level of exploration and mining, there are many more studies and surveys on the interaction of uranium mills and water resources than there are on uranium mines and water resources. With few exceptions, monitoring mine water quality has been related to NPDES permits.

When mines discharge water to open lands and water courses, 90 percent or more of it infiltrates the soil and the balance evaporates. Stable and radioactive contaminants subject to sorption are selectively concentrated in nearby soils, which become a local sink. Mobile constituents such as sulfate and chloride probably percolate to the water table along with the bulk of the water, which recharges nearby shallow aquifers downgrade from the mines. Although many areas in New Mexico, Texas, Colorado, Wyoming, and Utah have received mine water discharge, studies of contaminant accretion on soils and deterioration of groundwater quality have been rather limited. Widespread contamination of groundwater has not been documented, but there are indications that local surface water and groundwater quality have been adversely effected in Colorado, Wyoming, and Texas. Studies underway in New Mexico reveal, in at least two mining districts, groundwater deteriorating because of mine drainage. Significant increases in ambient uranium and radium occurred in the Shirley Basin uranium district of Wyoming because of initial strip mining and mill processing and, to a lesser extent, in situ leaching. The long-term significance of soil loading with stable and radioactive contaminants and their cycling through the terrestrial ecosystem, including the human food chain, has not been determined for uranium mining operations.

Discharges from model active surface and underground mines average 2 to 3 m^3/minute. In most cases, complete infiltration takes place in stream beds within 5 to 10 kilometers of the mines. However, when discharges from several mines are combined or if single mine discharge is several cubic meters per minute or more, infiltration and storage capacity of the alluvium in nearby channels is exceeded and perennial flows are created for distances of 20 to 30 kilometers. For example, underground uranium mines in the Grants Mineral Belt of New Mexico currently discharge 66 m^3 per minute. Of this, only 12 m^3 per minute are used in uranium mills; the balance is discharged to nearby washes or arroyos. Fourteen of the 20 active uranium mills make no use of mine water, which is associated with essentially every active underground mine and most active surface mines, particularly in Texas and Wyoming.

Annual contaminant loading from continuous discharge at a rate of 3 m^3/ minute from one surface mine in the Wyoming model area and dilution in flood flows with recurrence intervals of 2 to 25 years produce the loading and stream concentration values in Table 7.8. Chemical loading was calculated on a mass-per-time basis to estimate the effects of mine drainage.

For assessing environmental impacts, we assume that most contaminants remain on or near the land surface and are available for resuspension in periodic flash flooding in the sub-basin. Sorption, precipitation, and so on are assumed to render 90 percent of the radium-226 unavailable for further transport. Eighty percent of the sulfate is assumed to infiltrate and also becomes unavailable for further transport in flood waters.

Stream concentrations for uranium, zinc, cadmium, and arsenic are likely to be less than those shown because there will not be 100 percent resuspension of sorbed contaminants, and flood events with lesser return periods are also likely to disperse contaminants. The loading data are believed to be quite realistic; it is the temporal distribution and re-distribution of the contaminants that constitute a significant unknown. These preliminary results indicate contamination of surface water with uranium, radium, sulfate, and, to a lesser extent, with cadmium and arsenic in stream waters near the mine outfall. Subsequent dilution of these initial concentrations will occur as the flow merges with that of progressively larger streams in the downgrade direction, but cadmium and sulfate may exceed the drinking water standard in flood waters as far as the regional basin. Impoundment of these initial flows can be expected considering water management practices in semiarid rangeland areas like Wyoming. Therefore, further pathway investigations, based on field data, are needed.

For the model underground mining area, we selected the Ambrosia Lake District of New Mexico. We assumed that 14 mines discharged an average of 2 m^3/minute and that loading took place for two years prior to each flood. We then calculated concentrations in flood water for eight different cases-for 2, 5, 10, and 25 year floods (larger numbers indicating larger floods), with concentrations for each flood being calculated on the basis of both a 1-day and 7-day flood duration (see Table 7.9). Based upon these assumptions and calculations, it appears that concentrations in flood waters, particularly in the basin, may exceed established or suggested standards for uranium, radium, cadmium, arsenic, selenium, barium, and sulfate. However, precipitation and sorption, in addition to dilution farther downstream, probably will reduce these concentrations enough so that quality standards for drinking and irrigation water can be met. But

Table 7.8 Summary of contaminant loading and stream water quality from a model surface uranium mine

Annual Loading Per Mine [a] (Kg/yr)	Drinking Water Standard (mg/ℓ)	Concentrations in Basin and Regional Basin Flood Flows for Floods of 2, 25, and 100 Years Return Period, mg/ℓ			
		Basin		Regional Basin	
		Min	Max	Min	Max
Uranium 110	0.015/3.5/0.21 [b]	0.36	0.76	0.26	0.44
Radium-226 0.00065 Ci/yr	5 pCi/ℓ	2.1 pCi/ℓ	4.5 pCi/ℓ	1.6 pCi/ℓ	2.6 pCi/ℓ
TSS 32,955	---	107	228	79	131
Sulfate 2.76×10^5	250	900	1909	668	1098
Zinc 112.0	5.0	0.366	0.774	0.271	0.445
Cadmium 6.31	0.01	0.02	0.044	0.015	0.025
Arsenic 7.88	0.05	0.025	0.054	0.019	0.031

(a) Loading values shown for radium and sulfate are reduced to 10 percent and 20 percent, respectively, of the amount actually released by a mine. Irreversible sorption and precipitation affect radium and sulfate infiltrates to the water table.

(b) 0.015 mg/ℓ : Suggested maximum daily limit based on radiotoxicity for potable water consumed at a rate of 2 liters per day on a continuous basis. 3.5 mg/ℓ : Suggested maximum daily limit based on chemical toxicity and intake of 2 liters in any one day. 0.21 mg/ℓ : Suggested maximum daily limit based on chemical toxicity and intake of 2 liters per day for 7 days.

Table 7.9 Summary of contaminant loading and stream water quality from a model underground uranium mine

Annual Loading, Per Mine(a) (Kg/yr)	Drinking Water Standard (mg/ℓ)	Concentrations in Basin and Regional Basin for 1-day and 7-day Floods of 2 to 25 Years Return Period, mg/ℓ			
		Basin		Regional Basin	
		Min	Max	Min	Max
Uranium 1480	0.015/3.5/0.21(b)	6.9	7.1	0.045	0.046
Radium-226 0.0014 Ci/yr	5 pCi/ℓ	6.7 pCi/ℓ	6.9 pCi/ℓ	0.044 pCi/ℓ	0.044 pCi/ℓ
Lead-210 0.0014 Ci/yr	---	71.2 pCi/ℓ	73.4 pCi/ℓ	0.470 pCi/ℓ	0.0472 pCi/ℓ
Cadmium 7	0.01	0.03	0.03	0.0002	0.0002
Arsenic 13	0.05	0.061	0.063	0.00039	0.00041
Selenium 80	0.01	0.37	0.38	0.0026	0.0026
Molybdenum 300	---	1.4	1.4	0.0089	0.0093
Barium 850	1.0	4.0	4.2	0.26	0.27
Zinc 45	5.0	0.21	0.22	0.0014	0.0014
Sulfate 1.22×10^5	250	574	584	3.7	3.8
TSS 29,000	---	130	140	0.89	0.92

(a)Loading values shown for radium and sulfate are reduced to 10 percent and 20 percent, respectively, of the amount actually released by a mine. Irreversible sorption and precipitation affect radium and sulfate infiltrates to the water table.

(b)0.015 mg/ℓ : Suggested maximum daily limit based on radiotoxicity for potable water consumed at a rate of 2 liters per day on a continuous basis. 3.5 mg/ℓ : Suggested maximum daily limit based on chemical toxicity and intake of 2 liters in any one day. 0.21 mg/ℓ : Suggested maximum daily limit based on chemical toxicity and intake of 2 liters per day for 7 days.

more theoretical and field evaluations are needed to confirm this.

In situ leaching has contaminated local groundwater reservoirs. We expect that this will continue because leach solution excursions from the well field do occur and because injected constituents, especially ammonium, can not be fully recovered. The NRC and agreement States recognize this situation but consider the adverse impacts outweighed by the benefits of recovering additional uranium and developing a relatively new technology.

7.5.2 Effects of Mine Dewatering

Underground mines and most surface mines are dewatered to allow for excavation or shaft sinking and ore removal. The resulting low concentration and, oftentimes, large volume effluent discharges introduce substantial masses of stable and radioactive trace elements to local soil and water systems. This extensive use of soils in both the saturated and unsaturated zones as water and contaminant sinks requires further study to determine the environmental fate of those elements. In addition to local effects, the long-term impacts on regional water availability and quality are also important. The NPDES limits relating to surface discharges are, in terms of parameters and concentrations, different from one EPA region to another and should be reevaluated to more closely reflect the impact of contaminant concentration and mine discharge. In general, the uncertainties about the environmental impact of mine dewatering can be expected to increase; and additional, comprehensive investigations of its effects are necessary.

7.5.3 Erosion of Mined Lands and Associated Wastes

From initial exploration through retirement, mining, particularly surface mining, increases erosion and sediment yield. The most significant waste sources are access roads, drilling pads, and piles of overburden/waste rock and sub-ore. Sediment and associated contaminants are dispersed mostly through the overland flow of precipitation and snowmelt water. Erosion rates vary considerably with the characteristics of the source area, i.e., pile geometry, soil and rock characteristics, amount and type of vegetative cover, topography, and local climate. There is some erosion of all mine waste sources, although studies of ephemeral drainage courses downgrade from inactive mines in New Mexico and Wyoming usually reveal only local soil and water contamination and no significant off-site dispersal of contaminants. Proper reclamation, particularly grading and revegetation, markedly reduce erosion and, consequently, contaminant transport.

7.5.4 Exploratory and Development Drilling

The uranium industry has drilled approximately 1,300,000 exploratory and development drill holes through 1977. This amounts to about 430 drill holes per mine if averaged over all active and inactive mines. During the course of drilling, some land areas are disturbed to provide access roads to the drill sites and pads for the drill-rig placements. This has disturbed about 2500 km^2 (960 mi^2) of land for all drilling through 1977.

Drilling wastes accumulate at each drill site. Although these wastes are sometimes placed in trenches and backfilled after drilling, the general industry practice (observed from field studies and aerial photography), apparently, is to allow the wastes to remain on the surface, subject to erosion. The extent of radiological contamination from erosion of the remaining ore and sub-ore at development drill holes is not known.

The average drilling depth has increased with time and will probably continue to do so in the future. Deeper drilling will tend to increase the probability that several aquifers may be penetrated by each drill hole. Aquifers with good quality water may be degraded by being connected, via the drill holes, with aquifers of poor quality water. Current regulations require drill holes to be plugged to prevent interaquifer exchange, but often only the first one and one-half meters of the borehole will be plugged, and regulations do not effect past drill holes. Finally, it appears, from mine site surveys and aerial photography, that very few drill sites have been reclaimed.

7.5.5 Underground Mining

The land disturbed by individual underground mines varies from 0.89 to 17 hectares (2.2 to 42 acres) with an average of 9.3 hectares (23 acres). In addition, access roads to the mines consume about 1.1 hectares (2.7 acres), and mine subsidence disturbs about 1.5 hectares (3.7 acres). A total of about 12 hectares (30 acres) of land are disturbed by an average underground mine.

All underground uranium mining through 1977 has produced about 2.9 x 10^7 MT or about 1.8 x 10^7 m^3 of wastes. Some of these wastes, the sub-ores, contain elevated concentrations of naturally occurring radionuclides. The sub-ores usually are removed last in the mining process and dumped on top of the waste rock where they are subject to erosion. Some radiation surveys conducted around waste piles indicate that the sub-ores are eroding and contaminating land in addition to that disturbed by the mining activities.

During our field studies in Texas, New Mexico, Wyoming, and Colorado, we saw very few mine sites where reclamation had been completed or was in progress--especially at the inactive mine sites.

7.5.6 Surface Mining

The cumulative waste from surface mining uranium between 1950 and 1978 amounts to about 1.7 x 10^9 MT (1.1 x 10^9 m^3). Overburden is usually used to backfill mined-out pits during contemporary mining. At older inactive mines, the mine wastes were either used for pit backfill or completely disregarded. Erosion of these waste piles may cause substantial environmental problems.

The amount of land physically disturbed at a surface mine is highly variable. The area disturbed at ten surface mines was estimated to range from 1.1 to 154 hectares (2.7 to 380 acres), averaging about 41 hectares (101 acres) per mine site. Access roads disturb about 3 hectares (7.4 acres) per mine site, bringing the total average area physically disturbed to about 44 hectares (109 acres). Field surveys of inactive mine sites indicate that mine wastes (sub-ores) erode and contaminate land areas greater than those physically disturbed. The land contamination appears to have been caused by erosion of ore stockpiles, erosion of sub-ores, and dust losses from the actual mining process.

Very few if any inactive mine sites were reclaimed. Reclamation of any mine site will have to address the radiological aspects of the mine and its wastes.

7.6 Regulatory Perspective

Except for in situ leach mining, licensed by the Nuclear Regulatory Commission (NRC), uranium mining is not licensed, per se, by a Federal agency. However, three Federal statutes have particular relevance to uranium mining. First, the Federal Water Pollution Control Act as amended (1972) requires a permit for discharges to navigable waters. Second, the Clean Air Act amendments of 1977 require a permit for pollutant air emissions. Third, proposed regulations under the Resource Conservation Recovery Act of 1977 identify hazardous wastes and stipulate their disposal for uranium mining. When promulgated, these latter regulations will strengthen current Federal and State reclamation requirements.

In situ uranium mining is licensed by those states having agreement-state status with NRC. National Pollution Discharge Elimination System (NPDES) permits are issued by EPA approved states. No state issues mining licenses per se. However, most states require mining and reclamation plans, including bonding fees, for at least state-controlled lands. Most reclamation requirements provide erosion control through slope and vegetation standards. Arizona is the only uranium mining state without reclamation requirements.

7.7 Conclusions and Recommendations

The evaluation of the potential impacts of uranium mining was performed largely by means of analytical studies of model facilities. We believe that the results give an adequate representation of the industry. In order to determine the extent of possible problems, our studies were specifically designed to give conservative results. It should be recognized that actual mines may operate under conditions producing substantially smaller impacts than the results presented.

Compared to uranium milling, health and environmental effects of mining are not as well understood, despite the existence of over 3000 active and inactive mines. We have noted throughout this report instances of the absence or inadequacy of pertinent information.

7.7.1 Conclusions

7.7.1.1 Solid Wastes

Solid uranium mining wastes are potentially hazardous when used as building materials or when buildings are constructed on land containing such wastes. The hazard arises principally from increased risk of lung cancer due to radon-222. In a 1972 survey of communities in uranium mining regions, EPA and the former Atomic Energy Commission found more than 500 locations where such wastes had been used.

7.7.1.2 Airborne Effluents

a) Individuals living very near active underground mine exhaust vents would have an increased risk of lung cancer caused by exposure to radon-222 emissions. Surface mines and in situ mines are less hazardous, and inactive mines do not have significant radon-222 emissions. Other airborne radioactive emissions from all types of mines are judged to be smaller.

b) The number of additional cancers committed per year in the regional populations due to radionuclide air emission from the approximately 340 active mines and 3300 inactive mines was estimated to be about 0.6 cancers in 1978. This number of estimated additional cancers is small, about one-third of the estimated additional cancers in regional populations due to radon emissions from the 24 inactive uranium mill tailings piles addressed by Title I of the Uranium Mill Tailings Radiation Control Act (EPA 80). (These mill tailings piles represent about 13 percent of all tailings currently existing due to U.S. uranium milling and mining). These potential effects are not of sufficient magnitude to warrant corrective measures, especially considering the large number of sites involved.

c) The following were judged to cause an insignificant health risk for all types of mines:

1. airborne nonradioactive trace metals.
2. airborne combustion products from heavy-duty equipment operations.
3. nonradioactive emissions from in situ leach sites.

d) Airborne dust near large surface mines (primarily caused by vehicular traffic) may exceed the National Ambient Air Quality Standard for particulate matter.

7.7.1.3 Waterborne Effluents

a) We estimate that an insignificant health risk accrues to populations from waterborne radioactivity from an average existing mine.

b) Uranium mine dewatering and water discharges, which are increasing as more and deeper mines are created, may in the future have significant effects on water quality. Current treatment practices are controlling the release of radioactivity into surface waters.

c) Water in inactive surface and underground mines usually contains radionuclides and trace elements in concentrations comparable to groundwater in contact with ore bodies. Some abandoned underground mines in certain areas of Colorado and Utah probably discharge such waters to nearby streams and shallow aquifers. Available data is not sufficient to conclude whether or not there is a problem.

d) We could not determine, using models, that there is no health hazard to individuals who drink water drawn from such surface or underground sources. Water discharges from active mines to nearby streams and stream channels may extensively recharge shallow aquifers, many of which are either now used or could be used for drinking water. Such determinations must be made on a site-specific basis, and take account of the additive effects of multiple mines. These studies can be made easily a part of State or utility surveillance programs.

7.7.1.4 Exploratory and Development Drilling

Harm from effluents due to exploratory and developmental drilling is probably small compared to effects of operating mines. Under current regulations and practices, however, aquifers penetrated at different levels can mix, creating the potential for degrading high quality groundwater.

7.7.2 Recommendations to Congress

1) Based on this study, we do not believe at this time that Congress needs to enact a remedial action program like that for uranium mill tailings. This is principally because uranium mine wastes are lower in radioactivity and not as desirable for construction purposes as uranium mill tailings. Nonetheless, some mining waste materials appear to have been moved from the mining sites but not to the extent that mill tailings were.

2) Some potential problems were found that might require regulatory action but none of these appear to require new Congressional action at this time.

7.8 Other Findings

1) Regulations may be needed to control wastes at active uranium mines to preclude off-site use and to minimize the health risks from these materials. These regulations would need to address the use of the materials for construction purposes as well as ultimate disposal of the materials.

EPA proposed such regulations in 1978 under the Resource Conservation and Recovery Act (RCRA). In 1980, Congress amended RCRA to require further EPA studies before promulgating general regulations for mining wastes. An EPA study by the Office of Solid Wastes on all types of mines, including uranium mines, is currently being conducted. The amendment did not restrict EPA's authority to regulate use of uranium mine wastes in construction or reclamation of lands containing such wastes.

2) Standards are needed to control human exposure from radioactive air emissions from uranium mines. This is principally because of potential exposure to individuals living near large underground uranium mines rather than concerns regarding the exposure of regional populations. We have proposed such standards under Section 112 of the Clean Air Act.

3) EPA has conducted two field studies in 1972 and 1978 which define possible sites at which mine wastes may have been used in construction or around buildings. The information developed in these studies has been sent to State health departments. The States should conduct follow-up studies, as appropriate, to determine whether there are problems at these sites.

4) The adequacy with which NPDES permits protect individuals who may obtain drinking water near the discharge points for uranium mine dewatering should be evaluated by States. Under the Public Water Systems provision of the Safe Drinking Water Act, radionuclide standards now exist for drinking water.

5) Some site specific studies should be considered by States to determine the extent to which inactive uranium mines are significant water pollution sources.

6) States with uranium mines should determine the feasibility of control of fugitive dust from large surface mines and incorporate the recommendations in State Implementation Plans.

7) States should require borehole plugs in drilling operations that will prevent interaquifer mixing (exchange) and also seal drilling holes at the surface.

7.9 References

EPA80 U.S. Environmental Protection Agency, 1980, "Draft Environmental Impact Statement for Remedial Action Standards for Inactive Uranium Processing Sites (40 CFR 192), "EPA 520/4-80-011.